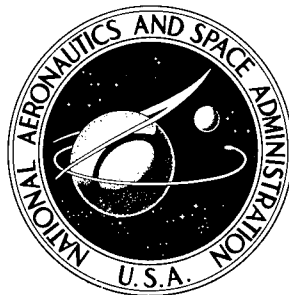


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SUMMARY

Cylindrical projectiles of polyurethane plastic, with a fineness ratio of $2/3$ and densities ranging from 1.17 gm/cc for the solid material to 0.065 gm/cc for the lightest porous material, impacted targets of 2024-T351 aluminum alloy and polycarbonate plastic at velocities from 3.45 to 7.08 km/sec . Solid projectiles with the fineness ratio appropriately reduced to give the same mass as some of the porous projectiles were also tested for comparison with the porous projectiles.

The results of the investigation indicated that the solid projectiles penetrated as deeply as the porous projectiles of the same mass, but their crater shapes and volumes were different. The depths of penetration in the two different target materials could be correlated on the basis of the density ratio raised to the $2/3$ power, without considering other physical properties such as strength. Comparison of the data of the present investigation with other plastic-projectile data indicated that the present data fall in low-speed or transition regions of impact.

INTRODUCTION

For deep space flights of long duration, the meteoroid hazard is a matter of concern to the spacecraft designer. Since meteoroid densities may vary, one aspect of this problem which must be considered is the effect of the meteoroid density on impact damage. In the laboratory, projectile-density effects have usually been studied with solid projectiles of materials varying widely in density. However, since cometary meteoroids are thought to be porous by many astronomers, the present investigation was focused on the effects of projectile porosity on impact damage. Polyurethane plastic was selected as the projectile material because it was available in rigid and flexible foams with densities ranging down to 0.065 gm/cc , the density of the parent (solid) material being 1.17 gm/cc . The densities suggested by various astronomers for cometary meteoroids range around 0.44 gm/cc (ref. 1).

The basic test projectiles were cylinders with fineness ratios of $2/3$. Solid projectiles of lower fineness ratio were also tested to determine the degree to which they would simulate porous projectiles of the same mass. Impact velocities varied from 3.45 to 7.08 km/sec . The targets were made of

2024-T351 aluminum alloy and polycarbonate plastic and were semi-infinite. Penetration data are presented and compared with the results of other experimental investigations.

NOTATION

d	projectile diameter, cm
l	projectile length, cm
$\frac{l}{d}$	projectile fineness ratio
p	depth of penetration, cm
$\frac{p}{d}$	penetration ratio
v	projectile impact velocity, km/sec
ρ_p	projectile density, gm/cc
ρ_{Al}	density of aluminum, 2.77 gm/cc
ρ_{pe}	density of polyethylene, 0.95 gm/cc
ρ_T	target density, gm/cc

APPARATUS AND TESTS

To avoid confusion, the projectile-target relationship will be defined as follows: The projectile (or model since the two are synonymous) will in all cases be the smaller body that impacts and forms a crater in the target, the more massive impacted body.

This investigation was conducted in two light-gas-gun ranges with bore diameters of 0.56 and 2.54 cm. The smaller gun was used to fire projectiles having densities of 0.26 gm/cc and greater into stationary targets. These models were sabot-mounted for protection and spin-stabilized to insure flat end-on impact. When the projectiles were too fragile to launch in this fashion (those with densities of 0.065 and 0.13 gm/cc), polycarbonate "targets" were launched from the 2.54-cm gun at foam models suspended by nylon filaments in the targets' path (see fig. 1). After being impacted, the targets were decelerated in air over a distance of about 100 meters and caught in a polystyrene-foam catcher. A more complete description of this technique is given in reference 2.

The basic test projectiles were polyurethane plastic, 0.318 cm in diameter and 0.212 cm long (fineness ratio of 2/3) with densities varying from

0.065 gm/cc for the lightest foam to 1.17 gm/cc for the parent material. Both rigid closed-cell and flexible open-cell foams were used for these projectiles. The impact velocity range for the investigation varied from 3.45 to 7.08 km/sec.

Two substantially different target materials were selected. First, it was felt that a frequently tested, structural alloy should be used to allow direct comparison of the results of the present investigation with previous ones. The aluminum alloy, 2024-T351 was thus chosen. Second, since it was obvious that the lighter and lower velocity foam projectiles would cause only slight damage in metallic targets, a second target material was required which would be sufficiently damaged to allow an overlapping comparison with the aluminum-target data. Polycarbonate plastic was chosen for the latter target material because its density (1.2 gm/cc) was close to that of the parent projectile material (1.17 gm/cc) and it had proven to be capable of withstanding the severe accelerations imposed by the 2.54-cm-diameter target launching gun. It is also resistant to ablation during the deceleration process and to damage during recovery. All targets of both materials were sufficiently large in comparison to the craters produced that they may be considered semi-infinite in size.

RESULTS AND DISCUSSION

At the outset it should be remarked that no differences could be discerned between the craters produced by either the rigid-foam or the flexible-foam projectiles of the same density. This result is not unexpected since the strength of even the rigid foam is quite low.

Plotted in figure 2 is the ratio of penetration depth to projectile diameter as a function of impact velocity for several projectile densities and for both target materials. As expected, the penetration ratio increases with impact velocity and projectile density. No aluminum-target data were obtained for the two porous projectiles of lowest density. For these cases, the aluminum targets had to be launched from the 2.54-cm-target launching gun and then decelerated in air after impact. The shallow craters produced by the low-density porous projectiles were obliterated by the ablation on the face of the aluminum targets during the deceleration process.

Figure 3 is a photograph of a section of a typical crater in polycarbonate plastic. For this case the projectile density was 0.13 gm/cc and impact velocity 7.08 km/sec, the highest velocity of this investigation. The crater is fairly broad and shallow because the density of the projectile is only about one-tenth that of the target. Because of the crater shape, it seemed reasonable to expect that the porous projectiles could be simulated by solid ones of lower fineness ratio and the same mass. Thus solid polyurethane discs of corresponding mass were used as the models. Plotted in figure 4 are the porous projectile data of figure 2 as well as the data obtained with the solid projectiles. It is apparent that as far as penetration ratio is concerned, the solid projectiles simulate the porous ones quite well; the crater profile and volume are not the same, as illustrated in figure 5 where the

crater profiles produced by the impact of a porous projectile and its solid counterpart in aluminum targets are compared. For the case shown, the crater volume for the porous projectile is roughly 1.4 times that of the solid projectile. Also, the solid-projectile crater is much more conical than that of the porous projectile apparently because of the low fineness ratio of the solid projectile, as previously observed in reference 3.

The penetrations in polycarbonate targets were adjusted to represent those in aluminum targets by multiplying the polycarbonate penetrations by the $2/3$ power of the ratio of polycarbonate density (1.2 gm/cc) to aluminum density (2.77 gm/cc). This adjustment is in keeping with the density effects reported in reference 4. The adjusted polycarbonate-target data are compared with the aluminum-target data in figure 6. The two sets of data agree quite well, in this presentation, with moderate scatter, leading to the conclusion that the $2/3$ -power target-density adjustment is valid for porous projectiles (and their solid simulating counterparts), at least within the scope of the present investigation.

The penetration data of figure 6 are compared in figure 7 with the data of reference 3 for projectiles of fineness ratio $1/3$ and with other data obtained by B. P. Denardo (private communication) for projectiles of fineness ratio $2/3$, 1.0, and 3.0. For those investigations, the projectile material was polyethylene plastic (density of 0.95 gm/cc) and the target material was 2024-T351 aluminum alloy. The penetration data from the present investigation were adjusted to be representative of the lower-density-projectile data of the reference investigations by employing the $2/3$ -power density adjustment (for projectile density in this comparison), again in keeping with the results of reference 4. To avoid a confusion of symbols, the test points of the present investigation are not shown; just the faired curves representing the best data fit on this log-log plot are presented. For simplicity, these curves are identified only by the appropriate values of fineness ratio for the simulating solid projectiles. The data points obtained by Denardo are, however, shown, similarly identified by projectile fineness ratio.

The primary conclusion that can be drawn from figure 7 is that the porous-projectile penetration data fall in a low-speed or transition region of impact, as described in references 3 and 4; that is, the penetration ratio depends strongly on velocity, especially for the lower projectile density. The data from the comparison investigations in figure 7 indicate a possible beginning of the hydrodynamic impact regime where the velocity dependence is roughly a $2/3$ -power dependence. It is apparent that, for the most part, a considerable increase in impact velocity is required to reach the true hydrodynamic impact regime for porous models.

Ames Research Center
National Aeronautics and Space Administration
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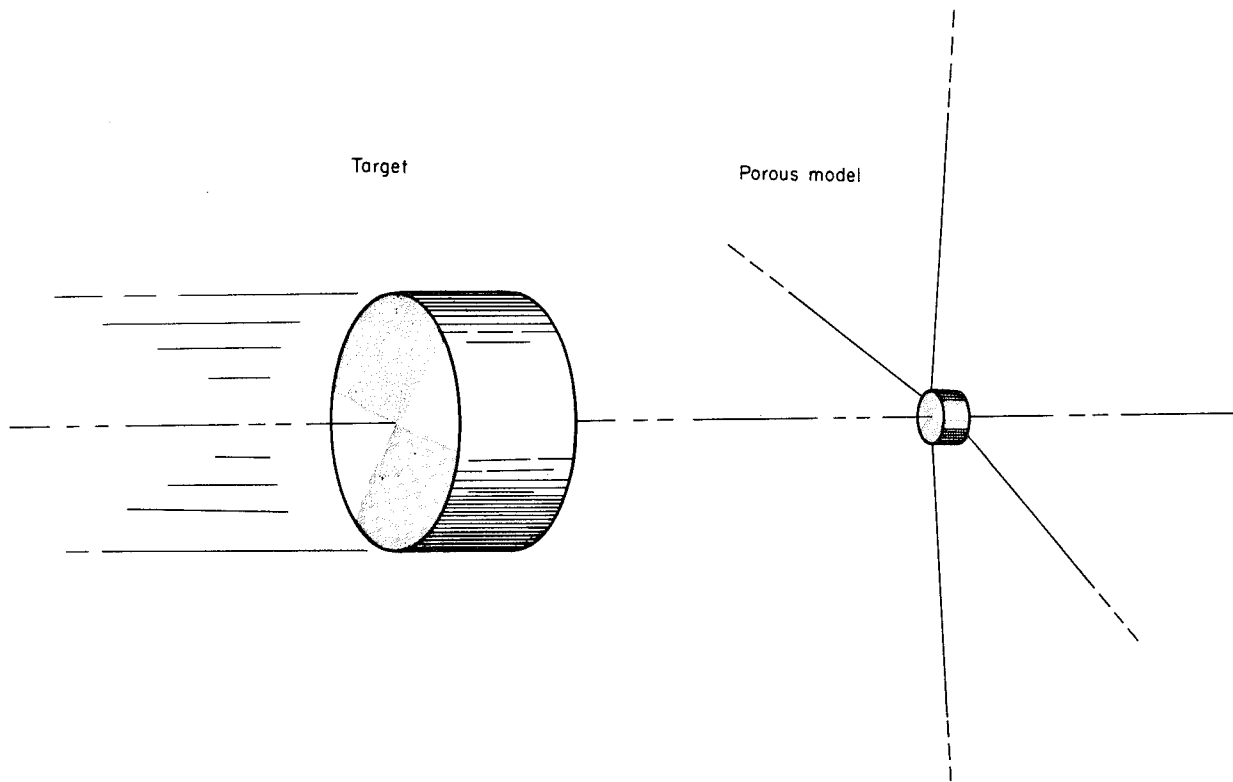


Figure 1.- Projectile-target configuration for low-density models.

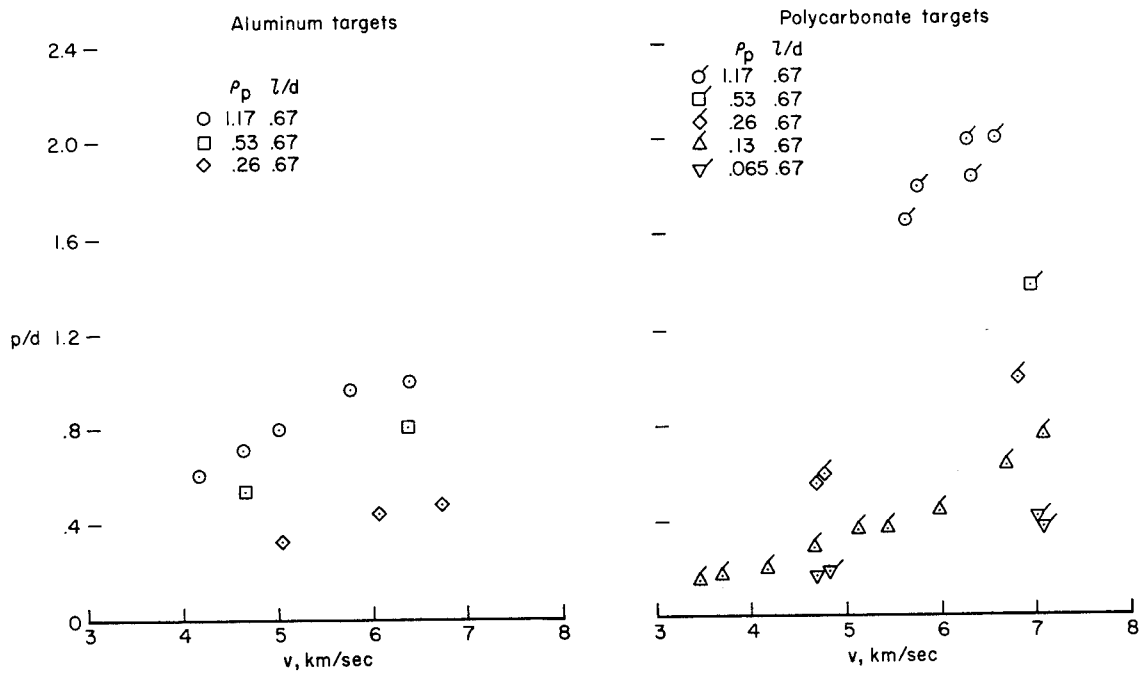


Figure 2.- Penetration ratio for the basic projectile.



Figure 3.- Crater in a recovered and sectioned target.

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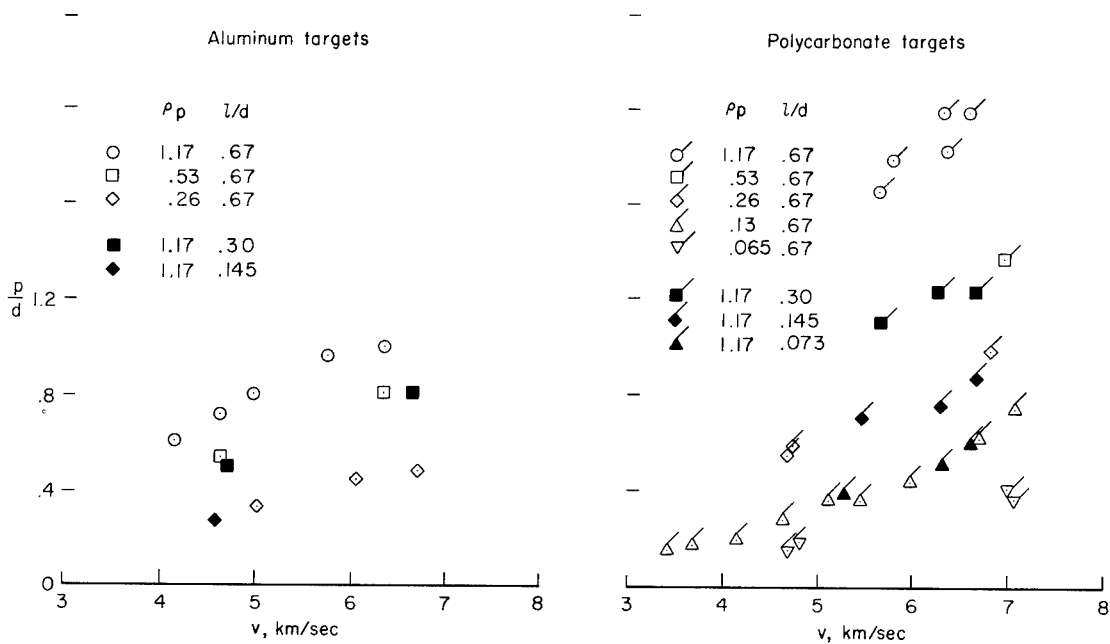


Figure 4.- Comparison of penetration ratio for the basic and simulating projectiles.

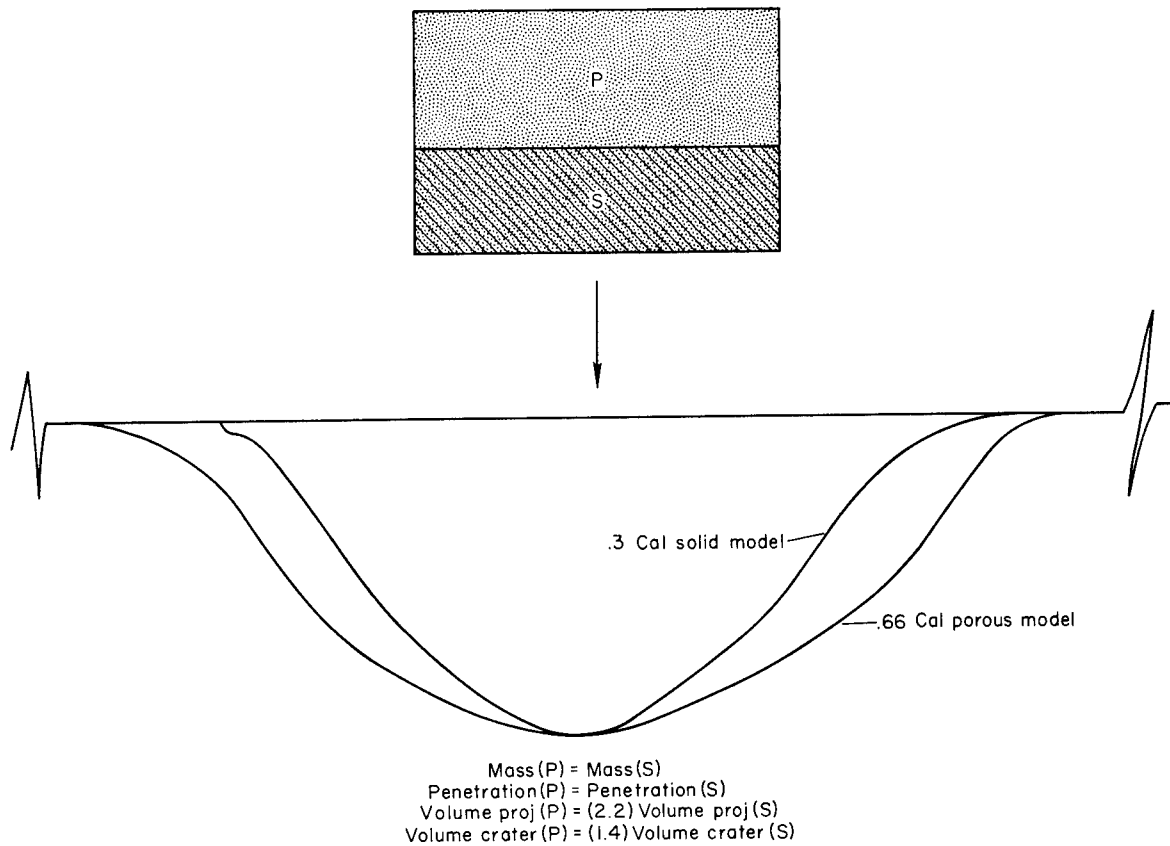


Figure 5.- Typical crater profiles in aluminum targets.

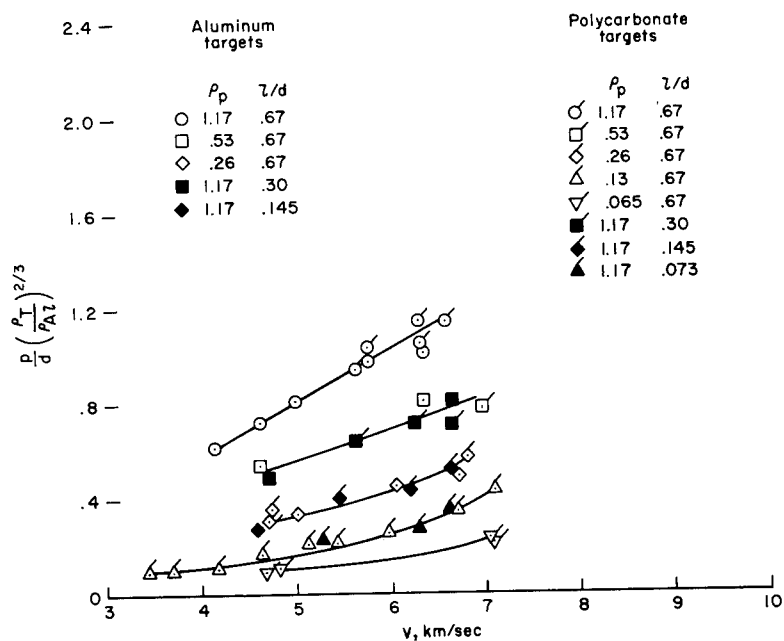


Figure 6.- Comparison of all penetration data adjusted to represent targets of aluminum.

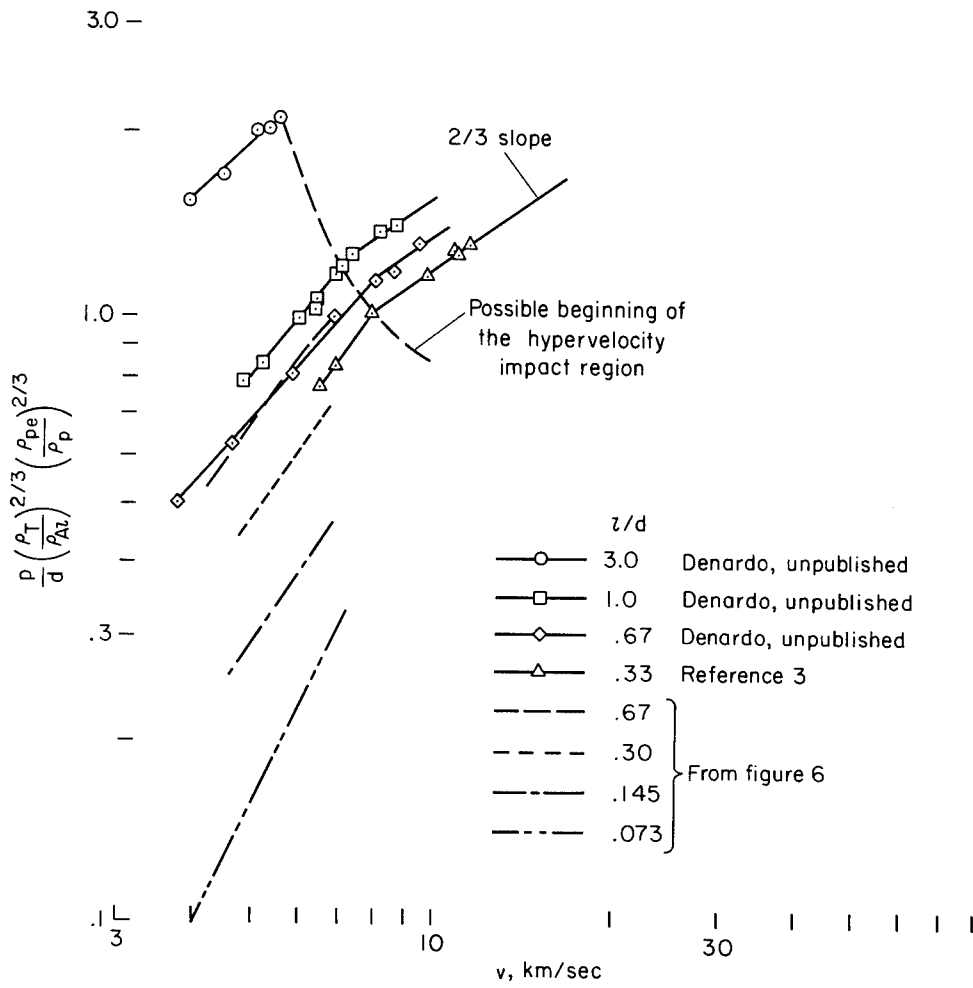


Figure 7.- Comparison of penetration data for several fineness ratios.